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Dairy buffalo life cycle assessment as affected by heifer rearing system

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ABSTRACT

In the near future dairy enterprises will have to meet increasing environmental regulations. Therefore, we aimed to evaluate the effects on the environment of dairy buffalo farming as affected by two different heifer rearing systems, free-ranging (FR) and confinement (C) using the Life Cycle Assessment approach. The primary data were collected from 32 subjects. The analysis included all of the farming phases (i.e. birth to weaning, weaning to 7–8 months of age, 7–8 months to puberty, puberty to first calving, lactation, dry period). During the heifer phase from 7 to 8 months of age to puberty, sixteen animals were group-housed and confined in an indoor slatted floor pen (4 m^2/animal) with an outdoor paddock (4 m^2/animal); 16 others were FR on a Mediterranean natural pasture. When pubertal, the animals from system FR were returned to the farm and reunited with the animals from system C. We used 1 kg of fat and protein corrected buffalo milk (FPCM), with a reference milk fat and protein content of 8.3% and 4.73%, respectively, as functional unit. Impact categories investigated were Climate Change (CC), Terrestrial Acidification (TA), Marine Eutrophication (ME), Agricultural land occupation (ALO), Water depletion (WD). At category level system FR showed a reduction of the impact in terms of CC (9%), TA (10%), ME (6%) and WD (11%), whereas ALO was 7% higher as compared to system C. In conclusion, we clearly showed that the conduction of part of dairy buffalo farming (i.e. the unproductive phase from 7 to 8 months of age to puberty) on natural pasture is possible and it also allows the reduction of several sources of pollution while reducing the production costs, hence the economic sustainability. Although this system requires a greater use of land, parameters concerning the quality of land use should be included for a more accurate assessment of this aspect.

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1. Introduction

Countries adhering to the United Nations Conference on Climate Change (COP21) agreed to keep the increase in the global temperature below 2 °C. The main greenhouse gas (GHG) emissions attributed by the International Panel of Climate Changes (IPCC) to the agricultural sector are methane (CH_4) and nitrous oxide (N_2O). Animal enterprises are responsible for the production of GHG under the form of CH_4 from enteric fermentations (EF), N_2O deriving from the use of nitrogenous fertilizers, and CH_4 and N_2O emitted from manure managed under intensive farming conditions or direct manure deposition on pastures in more extensive systems (O'Mara, 2011). Animal productions are responsible for 8–11% of GHG emissions as assessed by IPCC (2006a). In Europe, within the animal production sector, dairy milk production shows the highest environmental impact (28–30%), along with beef (28–29%) and pork production (25–29%) in terms of GHG emissions (Weiss and Leip, 2012).

Although in 1991 the Council of the European Communities issued the directive 91/676/EEC in order to reduce nitrate leaching and the consequent water pollution caused by agricultural practices, including those concerning animal production, by setting thresholds of spreadable organic N per hectare per year, no specific rules concerning the environmental impact of dairy enterprises is currently available. Nevertheless, in the near future dairy enterprises will have to meet an increasing number of environmental rules including limits on GHG and other noxious gas emissions (e.g. NH_3) and restrictions on nitrate (NO_3^-) leaching and phosphate (PO_4^{-3}) run-off (European Council, 1991; Lovett et al., 2008). Life

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Cycle Assessment (LCA) has been widely used to assess the impact of various milk production systems on the environment. In particular, LCA allowed the comparison between organic and conventional systems (e.g. Cederberg and Mattsson, 2000; Thomassen et al., 2008) as well as the evaluation of the environmental performance of different dairy (e.g. O'Brien et al., 2012) and meat enterprises (e.g. Bragaglio et al., 2018).

For animal based production enterprises the identification of best practices from an environmental point of view is not simple as different systems often imply trade-offs between different forms of impact, some systems may favour biodiversity conservation and carbon sequestration, in others food production may be more efficient (Galka, 2004). For instance, systems based on free-ranging may show higher environmental performances due to the low inputs needed in the production process, albeit requiring more land. However, land can be used for several different purposes and if land use options are included in the assessment, results on environmental performances may change (Thomassen et al., 2008).

In Italy buffalo farming represents one of the most important dairy enterprises (AIA, 2013). It has been conducted for centuries in extensive conditions based on marshland environments. In the last forty years the increasing demand of mozzarella cheese induced a concomitant increase in the number of buffaloes, which in Italy increased from about 103,000 in 1980 to approximately 378,000 head in 2015. These animals are distributed in about 2455 farms mainly located in central-southern Italy (Italian Ministry of Health, 2015). This geographical area comprising Campania, Lazio, Apulia and Molise regions has been identified for the production of the cheese “Mozzarella di Bufala Campana” registered in the European Union's list of Protected Designation Origin products. The average production in 2013 was 2222 kg of milk per 270-day lactation (AIA, 2013). As a consequence, buffalo farming has moved to more intensive farming conditions with a feeding system based on three different rations corresponding to the three main buffalo productive stages (lactating cows, dry cows, growing heifers). Maize silage and ryegrass hay represent the main forages of their diet, whereas concentrates are only given to lactating buffalo cows (Sabia et al., 2015a). In these farming conditions animals have no access to pasture and water for wallowing. Such management changes concerned all animal categories, including juvenile, non-lactating animals such as heifers, which neither necessitate, unlike buffalo cows, milking facilities and feeding supplementation to fulfil the increased requirements induced by milk production, nor they need, unlike buffalo calves, particular protection from climate extremes and predator attacks.

Despite the economic relevance of buffalo farming in Italy and the increasing interest in this species worldwide, only few studies on its environmental impact as assessed by LCA have been conducted so far (Pirlo et al., 2014a; b; Sabia et al., 2018). In particular, Pirlo et al. (2014a) noted a high degree of variability between farms, which suggests the potential for improvements of the environmental performances of buffalo farming. However, the authors did not identify or suggest ways to pursue such improvements. In addition, Pirlo et al. (2014b) observed that the second most important source of GHG emission in intensive buffalo farming was off-farm feed production while also suggesting that at least the impact of the replacement should be included in the calculations. Extensive farming practices may reduce environmental impact and production costs (Nilsson et al., 2004), while promoting animal welfare (Sabia et al., 2014) and product differentiation through quality assurance (Napolitano et al., 2013). These practices may be conveniently used for species well adapted to the environment, such as buffaloes, and non-productive animal categories, such as heifers (Sabia et al., 2014). Therefore, the present study aims to evaluate the effects on the environment of dairy buffalo farming using a breakdown approach thus taking into account each single animal category, including the unproductive ones. In addition, we evaluated whether the adoption of a free-ranging system for the only suitable category in intensively conducted farms (i.e. heifers) may reduce the environmental impact of the entire production process as assessed by Life Cycle Assessment.

2. Materials and methods

LCA is the assessment of inputs, outputs and environmental impacts of any production systems through production, usage, and disposal (Guinée et al., 2002). The ISO standards (ISO, 2006a; b) describes four distinct phases of LCA: 1) identification of the aim, functional unit, and limits of the system; 2) analysis of the inventory (including in and output data collection for all processes); 3) assessment of the environmental impact; 4) result interpretation.

2.1. System boundary definition

The analysis included all of the farming phases (i.e. birth to weaning, weaning to 7–8 months of age, 7–8 months to puberty, puberty to first calving, lactation, dry period). Apart from the heifer phase (7–8 months to puberty), which was conducted either on pasture (Gioi, Salerno province, Italy, 600 m ASL), in or in confinement (Eboli, Salerno province, Italy, 5 m ASL), all of these phases were conducted in confinement. The two entire productive processes, one including free-ranging heifers, the other including confined heifers, were identified as system FR and system C. The boundaries of the two systems are depicted in Fig. 1. Primary data on feeding and energy consumption were directly collected on farm from birth to the end of the first lactation, including the subsequent dry period. The data concerning the heifer phase were collected between the ages (mean ± SE) of 235 ± 18 days and 675 ± 11 (age of puberty) for system FR, and between the ages of 236 ± 17 days and 667 ± 11 days (age of puberty) for system C, corresponding to the period September 2010–October 2011. The reference data were retrieved from Sabia et al. (2014). We took into account any on-farm activities (such as feed production, electricity, fuel and energy use, manure and animal management), and the corresponding emissions. We also considered the consumption of energy and the emissions from activities conducted off-farm. In particular, the data concerning the production of bedding materials, fodders, pesticides, fertilizers and water consumptions were retrieved from Ecoinvent database, whereas fuel, electricity and concentrate consumptions were primary data. The transport of off-farm feeds and bedding material along with the transport associated with the transfer of buffalo heifers from the farm to the pasture were also included in the estimate. The heifers were considered pubertal when plasma progesterone levels (P4) were above 1 ng/ml for the first time and the following sampling points showed a cyclic trend (Terzano et al., 2007).

2.2. Functional unit definition

We used 1 kg of fat and protein corrected buffalo milk (FPCM), with a reference milk fat and protein content of 8.3% and 4.73%, respectively, as functional unit. Raw milk was transformed into FPCM using the following formula (Di Palo, 1992):

FPCM (kg/year) = ({[(g of fat/L − 83) + (g of protein/L − 47.3)] × 0.00687} + 1) × milk production (kg/year). Milk production was 2451 and 2390 kg/animal/lactation for system FR and system C, respectively.

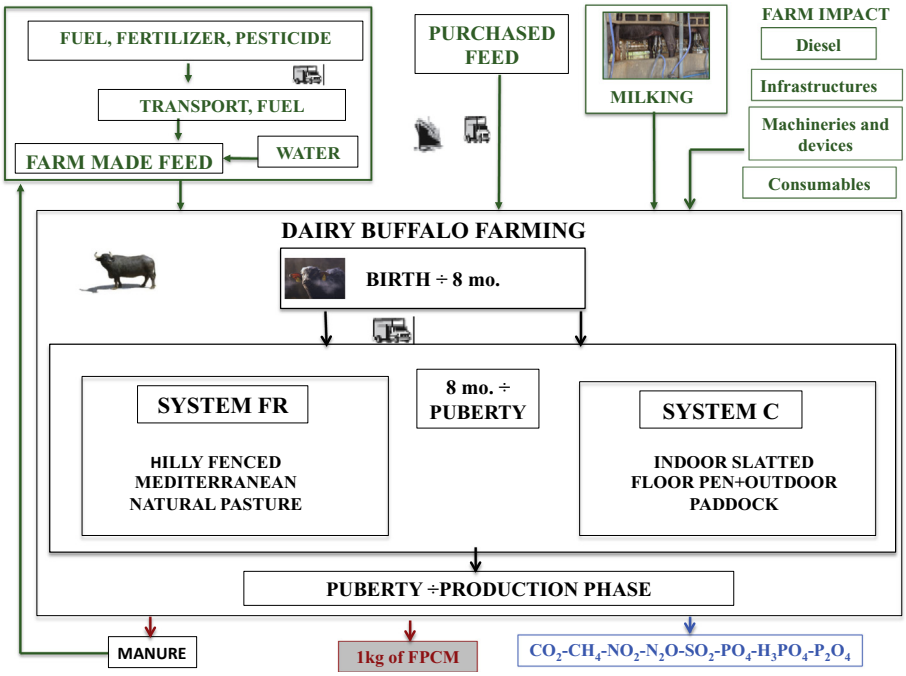

Fig. 1. Boundaries of the dairy buffalo farming system.

2.3. Inventory analysis

The inventory comprised the data from 32 animals (data related to inputs are summarized in Table 1). Calves were allowed to ingest colostrum and then separated from their mothers within 24-h after birth. After separation the animals were kept in individual cages (1 × 2 m) for 8 weeks and then housed in groups of 8 in straw-bedded pens (5 × 8 m). They were fed reconstituted milk (6 l/calf/day at 18% DM). After 4 weeks, the amount of milk substitute was gradually reduced while meadow hay and concentrate administration increased (Table 1). After weaning (90 days) the animals were grouped (16 animals per group) in two slatted floor pens (6 × 6 m) with and outdoor paddock (6 × 6 m). At 7–8 months the animals were re-grouped to obtain two groups homogenous for age and body weight (192 ± 36 and 187 ± 33 kg for systems FR and C, respectively; T-test, $P > 0.05$). Sixteen animals (system C) were kept in an indoor slatted floor pen (8 × 8 m) with an outdoor paddock (8 × 8 m); sixteen others (system FR) were moved to a hilly fenced Mediterranean natural pasture of 40 ha unsuitable to crop production, which was neither irrigated nor inorganically fertilized. They also had a free-stall open-sided barn with earth floor (18 m^2/head) and an ample outdoor paddock (70 m^2/head).

At puberty the heifers reached a weight of 402 ± 3 and 382 ± 3 kg in systems C and FR, respectively. Differences between

Table 1
Inventory analysis of the single phases and of the entire process of systems free-ranging (FR) and confined (C).

	0-3 months	3-8 months	Heifers FR	Heifers C	Gestation	Lactation	Dry period	System FR (entire process)	System C (entire process)
Feed consumption (kg DM[a]/head)									
Milk powder	100	–	–	–	–	–	–	100	100
Maize flour	7	66	–	–	126	545	–	744	744
Maize Silage	–	760	–	4400	2100	5400	840	9100	13,500
Straw	–	–	–	342	–	–	840	840	1182
Meadow hay	25	300	540	–	1350	1215	–	3430	2890
Soybean meal	3	132	–	209	264	508	10	914	1123
Barley flour	2	2	119	181	–	117	–	119	302
Wheat	–	–	–	88	90	200	67	357	445
Beet pulp	–	–	90	–	–	–	–	90	–
Sun flower	3	6	–	–	11	–	94	114	114
Wheat flour shorts	–	96	81	–	192	544	67	693	612
Permanent pasture	–	–	5840	–	–	–	–	5840	–
Feed nutritional value, % DM[a]								n.a.	n.a.
Crude protein	23.1	15.6	10.8	14.2	12.8	15.0	8.8	n.a.	n.a.
Crude fiber	7.2	24.2	28.3	24.4	27.9	22.1	33.8	n.a.	n.a.
Neutral detergent fiber	14.4	47.1	57.8	42.5	52.4	42.3	56.1	n.a.	n.a.
Ash	7.0	7.4	7.1	5.5	8.1	6.4	7.2	n.a.	n.a.
Starch	5.2	17.4	5.6	21	13.0	25.1	9.1	n.a.	n.a.
MFU[b]	0.93	0.79	0.58	0.80	0.71	0.88	0.56	n.a.	n.a.

n.a. = not applicable.
[a] DM = Dry matter.
[b] Units/kg dry matter; 1 Milk Forage Unit = 7.11 MJ net energy.

groups were significant (T-test, $P < 0.05$) due to the higher feeding regimen of system C, the higher physical activity performed while grazing by system FR and the lower environmental temperature of the hilly area where this group was located. Nevertheless, these animals reached puberty at an age not significantly different from that observed in system C (T-test, $P > 0.05$). When pubertal, the animals from system FR were returned to the farm and reunited with the animals from system C. They were inseminated by a buffalo bull and kept in loose housing conditions (indoor: 7 m^2/head, outdoor: 16 m^2/head). After parturition they were kept in loose housing conditions (indoor: 8 m^2/head, outdoor: 25 m^2/head) and subjected to routine milking twice a day. At the end of lactation the animals were dried-off and kept in loose housing conditions (indoor: 7 m^2/head, outdoor: 50 m^2/head).

The components and chemical composition of the ration offered to the animals are reported in Table 1. From December 2010 to March 2011 animals from system FR grazed on pasture and were also supplemented with dehydrated beet-pulps, wheat flour shorts and meadow hay.

Total emissions were estimated for each system (FR and C) including fuel combustion, EF, manure management (handling, storage and application to the field) and emissions occurring as a consequence of chemical fertilisation and deposition of urine and faeces during grazing. Methods and emission factors are listed in Table 2.

CO_2 emitted during energy consumption, either directly from the combustion of fossil fuels or indirectly from electricity use, was estimated taking into account the litres of diesel fuel and the kWh of electricity consumed throughout farm operations. The amounts of purchased fuel were summed up to estimate the fuel used for general agricultural practices and animal feeding. As suggested by ENAMA (2005), we used a standard value of 0.85 kg per litre as diesel density, and a 3.13 eq. emission factor to estimate CO_2 release from the combustion of 1 kg of diesel. As to the electricity mix, we used the Italian emission factor (0.47 eq.) suggested by Cóndor (2011).

CH_4 emissions from EF, stored manure and manure deposited by animals on pasture were calculated following the method Tier 2 IPCC (2006a), which is based on herd dry matter intake (DMI). Phosphorus loss in the form of phosphate (PO_4^{3-}) was estimated by the methodology proposed by Nemecek and Kägi (2007) for run-off and leaching. This method calculates the amount of phosphorus excreted by the animals and applied to the field as well as the input from chemical fertilizers.

Direct N_2O emissions were calculated from manure storage (system C) and faecal deposition on the pasture (system FR) using the excretion of nitrogen (N). Nitrogen excretion was calculated with the equation 10.25 (Tier 2 method) by using default values of total annual nitrogen excretion for each livestock species/category (T) that is managed in each manure management system for FR and C. The latter was calculated by subtracting the output of N in products (increment of live weight in kg from 7 to 8 months of age to puberty) to the total N intake (this calculation was based on the dry matter ingested by the animals and the N content of the diet). Grass availability in dry matter (DM/ha) and chemical compositions of the pasture were measured using iron-fenced net boxes randomly placed on the grazing area. The family of Gramineae prevailed in the months of November (65%) as compared with Leguminosae (4%), whereas the percentage incidence of these plants increased in spring (41%), when the Graminae were less represented (24%). Herbage (system FR) and ration (systems C and FR) samples were oven-dried and ground for the determination of DM content. Crude protein was determined using a Foss Tecator AB (Hoeganaes, Sweden) for laboratory analyses. DM intake and crude protein ingestion were estimated on the basis of the body weights (91 g DM kg^{-1} body $weight^{0.75}$), as suggested by National Research Council (2001). Only for systems C, estimated DM intakes were verified by comparison with the actual DM consumptions as routinely registered in the barn (delivered in the trough − trough residuals). Faecal samples were collected from the rectum and stored at − 20 C°. Nutrient *in vivo* digestibility was measured using acid-insoluble ash as internal marker. Feed and faecal samples were analysed in duplicate using the procedure suggested by Van Keulen and Young (1977). For system C the main feeds used in the ration were produced on-farm (maize silage, meadow hay and straw, whereas soybean meal, barley and wheat for system C and beet pulp and wheat flour for system FR were produced off-farm. We used the emission factors as proposed by IPCC (2006a) for liquid slurry storage (system C) and solid manure (system FR) systems. Direct and indirect N_2O emissions from the field also occur after the application of organic and inorganic fertilisers. We used the Tier 1 method to estimate direct N_2O emissions from the inputs of

Table 2
Emission factors and equations used for the estimation of environmental emissions of each pollutant.

Pollutant	Source	Equation	Emission Factor	Reference
kg CH_4	Enteric	CH_4 = kg DMI $herd^{-1}$ * 18.45 (Gross Energy MJ kg^{-1} DMI) * Ym%/55.65	Ym = (9.75−0.05 * DE%)	IPCC (2006a) Opio et al. (2013)
	Storage and Pasture	CH_4=VS * B_0 * 0.67 * MCF/100 * MS	MCF pit storage = 27 MCF pasture = 1.5 MS pit storage = 20% MS pasture = 5%	IPCC (2006a)
kg N_2O direct	Storage	N_2O = Nex (conf. syst.) * MS * EF * 44/28	0.02	IPCC (2006a) Cóndor et al. (2008a)
	Pasture	N_2O = Nex (pasture) * MS * EF * 44/28	0.007	IPCC (2006a)
kg N_2O indirect	Storage	$N_2O_{(G)}$ = Nvolatilization * EF * 44/28	0.01	IPCC (2006a)
	Field/Pasture	$N_2O_{(ATDN)}$ = [(Nsn * Frac_GasF) + ((Non + Nprp) * Frac_GasM)]*EF * 44/28	0.01	IPCC (2006b)
		$N_2O_{(L)}$ = (Nsn + Non + Ncr + Nsom + Nprp) * Frac_Leach * EF * 44/28	0.0075	IPCC (2006b)
kg NH_3	Storage	Nvolatilization = Nex (conf. syst.) * MS * Frac_GasMS/100 *17/14	Frac_GasMS solid storage: 40	IPCC (2006b)
kg CO_2-eq	Diesel use	CO_2-eq. = l diesel * EF	3.13	APAT (2003)
	Electricity use	CO_2-eq. = kWh * EF	0.47	Cóndor (2011)

Ym = methane conversion factor; DMI = Dry matter intake; MCF = Methane conversion factor; MS = Manure management system usage; VS = volatile solids (3.9 kg/hd/day); B_0 = maximum methane producing capacity (0.1 m^3 CH_4/kg VS); Nex = annual N excretion for livestock category; Nsn = annual amount of synthetic fertiliser N applied to soils, kg N yr^{-1}; Non = annual amount of animal manure, compost, sewage sludge and other organic N additions applied to soils kg N yr^{-1}; Ncr = annual amount of N in crop residues including N-fixing crops, and from forage/pasture renewal, returned to soils, kg N yr^{-1}; Nsom = annual amount of N in mineral soils that is mineralised, in association with loss of soil C from soil organic matter as a result of changes to land use or management, kg N yr^{-1}; Nprp = annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock, kg N yr^{-1}, DE = Digestible Energy.

mineral and organic N under the form of crop residues, N mineralisation and fertilisers, as suggested by the IPCC (2006b). Direct and indirect N_2O emissions occurring on pasture during grazing were estimated following the IPCC methodology. We estimated the amount of nitrous oxide emitted from manure storage and management based on total N excretion and the country-specific emission factor of 0.02 kg of $N-N_2O$/kg of excreted N for Italy (Cóndor et al., 2008a). As to direct N soil deposition, we used an emission factor of 0.0125 kg $N-N_2O$/kg N (Cóndor et al., 2008a). Indirect emissions of N_2O were estimated according to the method suggested by IPCC (2006b) based on NO_3^- leaching-runoff, and re-deposition of volatised gases to soils and waters. In particular, for indirect deposition from the atmosphere an emission factor of 0.01 kg N_2O/kg N was used, whereas of 0.025 $N-N_2O$/kg N was used for N leaching-runoff as suggested an Italian country specific emission factor by Cóndor et al. (2008a). The volatilization of NO_x and NH_3 occurring during the application of mineral and organic fertilisers was assessed using the emission factor suggested by Tier 1 in the EEA (2009) guidebook.

Data on land occupation were predominantly primary and based on natural pasture production and production on-farm of the main feeds used in the ration in system C (maize silage, meadow hay and straw). However, soybean meal, barley and wheat for system C and beet pulp wheat flour for system FR were not produced on-farm and data were estimated.

As it was not possible to get primary data concerning the consumption of diesel fuel and electricity consumptions of individual animals, we measured these data at farm level and then allocated them on the basis of the livestock units (LU) involved in each phase. In the farm there were in total 500 cows, 15 bulls, 75 heifers, 150 young female stock and 15 young bulls. Cow replacement was 15% with a mean productive life of 6.7 lactations; therefore, an allocation was also performed by attributing 15% of the environmental impact generated by the animals during the unproductive phase (birth to first calving) to the process. Consumptions of diesel fuel per head were 81 and 95 L for systems FR and C respectively, whereas electricity consumptions per head were 120 and 127 kw for systems FR and C, respectively.

Culled buffalo cows and male calves have a very low economical value and represent less than 2% of the production value. Therefore, no economical allocation was performed and meat production was considered negligible. Primary data on feeding and energy consumption were directly collected on farm.

2.4. Environmental assessment

The environmental assessment was based on the following impact categories and units:

- Climate Change: kg CO_2-eq
- Terrestrial Acidification: kg SO_2-eq
- Marine Eutrophication: kg N-eq
- Agricultural land occupation: m^2 year
- Water depletion: m^3

The life cycle assessment was carried out with the assistance of a commercial software package: SimaPro 8.01 PhD. The ReCiPe Midpoint (H) V1.10/Europe Recipe H module of this package was used (Lamnatou et al., 2016), in the evaluation of Climate Change, Terrestrial Acidification, Marine Eutrophication, Agricultural land occupation and Water depletion.

2.5. Monte Carlo analysis

A Monte Carlo analysis was performed using the SimaPro software. This analysis is a numerical way to process uncertain data, establish an uncertainty range in the calculated results and to assess the significance of the differences between the environmental performances of the two systems under evaluation.

3. Results and discussion

The total environmental impact of the process is presented in Table 3. The Table shows a higher impact of system C as compared with system FR in all of the impact categories except for agriculture land occupation, which instead was higher in system FR. In a previous study the free-ranging system proved to be able to lower the production costs from an economic and productive point of view, as part of the feed were directly gathered from pasture, while allowing a satisfactory somatic development and reproductive performance of the animals (Sabia et al., 2014).

A detailed discussion on the environmental performance of the two production systems in each impact category is given below.

3.1. Climate change (CC)

The environmental impact generated by the two global processes, 1 kg of FPCM is reported in Table 3. The use of free ranging from 8 months to puberty determined a 9% reduction in terms of CC. This result may be mostly attributed to the fact that in FR the transport of raw materials was much less relevant. In a previous study Pirlo et al. (2014a) observed an average environmental impact of intensive dairy buffalo farming of 5.07 kg CO_2 – eq per kg of FPCM. In our study the intensive global process produced 4.01 kg CO_2 – eq per kg of FPCM. However, the same authors observed levels of kg CO_2 – eq per kg of FPCM below 4.01 in two out of six intensive farms. Therefore, our results are not necessarily in contrast with those of Pirlo et al. (2014a), as a certain degree of variability between dairy enterprises is often observed.

The lactation phase produced 1.59 and 1.69 kg CO_2 – eq per kg of FPCM for systems FR and C, respectively (Table 3), corresponding to about 42% of the entire process. Such different impacts may be attributed to the higher milk production observed in system FR as possible consequence of the higher somatic development and animal welfare (Sabia et al., 2014). In this phase, feeding accounted for 59%, followed by enteric emissions (25%) and overall activities (12%). Feeding plays an important role in affecting the environmental impact of buffalo farming, as it is mainly based on maize silage which is a demanding crop in terms of organic and inorganic

Table 3
Environmental impact of the single phases and of the entire process of systems free-ranging (FR) and confined (C) for the production 1 kg Fat and protein correct milk.

Impact categories	Units	System FR (entire process)	System C (entire process)	Lactation phase - FR	Lactation phase - C	Heifer phase - FR	Heifer phase - C
Climate Change	kg CO_2-eq	3.68	4.01	1.59	1.69	1.03	1.33
Terrestrial Acidification	g SO_2-eq	14.17	15.58	7.01	7.40	0.58	4.64
Marine Eutrophication	g N-eq	17.56	18.62	9.16	9.68	0.93	3.44
Agricultural Land occupation	m^2 year	10.37	9.64	3.70	3.91	8.84	0.53
Water depletion	m^3	4.01	4.46	2.26	2.39	0.17	1.64

fertilisation and water for irrigation. This impact may be mitigated by replacing maize silage with a less demanding crop such as triticale silage, whereas recent studies indicate that the inclusion of more digestible forages in ruminant diets may reduce CO_2 emissions (Sabia et al., 2015b).

In the heifer phase 1.03 and 1.33 kg CO_2 − eq per kg of FPCM were produced by FR and C systems, respectively (Table 3), with a reduction of 33% when the heifers are allowed to free range.

Table 4 shows the contribution of the different chemical components of the production chain to the CC. The CC was higher in heifers from system C than in animals from system FR. However, the FR system produced 10% more CC emissions than system C in the early stages of farming (age = 395 ± 18 d, weight = 277 ± 40) when the animals were supplemented with dehydrated beet-pulps, wheat flour shorts and meadow hay. This result may be attributed to the fact that in these early stages the activities related to movements outside the farm, such as buying food, were higher in system FR. Nevertheless, this system determined an 8% reduction of total CC emissions as compared with system C. Based on these results, Sabia et al. (2014) noted that animals from system FR were more efficient, as these animals reached the age of puberty with lower CP (261.1 ± 14.5 vs. 281.6 ± 14.5 kg, respectively) and energy intakes (1554.8 ± 74.9 vs. 1583.2 ± 74.9 MFU) as compared with heifers from system C. Biogenic methane from enteric fermentation and manure was the largest contributor to CC in both systems, followed by emissions of carbon dioxide from fossils. The main contribution of methane biogenic emissions was due to enteric fermentation. Although system FR at least partly relied on a food residue (beet pulps), and a major part of the environmental impact was attributed to the production of sugar (Elferink and Nonhebel, 2008), free-ranging animals produced about 30% more than system C, due to the fact that animals ingested a larger amount of fibrous feed as compared with heifers from system C, and energy digestibility is lower as compared with concentrates. CH_4 is produced in ruminant as a direct consequence of fiber hydrolysis (Pirlo et al., 2014b). In particular, the rumen is the site where a number of fermentative processes occur thus allowing to obtain nutrients such as fatty acids and proteins of bacterial origin from vegetal fibres (Zahedifar et al., 2002). Emissions of biogenic methane from manure management was higher in the system C with respect to the system FR due to the storage of liquid and solid manure under the slatted floor and its subsequent handling and spreading on land. The results showed values slightly lower than those observed by Cóndor et al. (2008b). These different results may be attributed to the fact that these authors estimated an average weight of 405 kg for buffaloes aged 1–3 years, corresponding to an emission factor equivalent of 73.42 kg CH_4. Conversely, in our study we regularly recorded the weights of buffalo heifers from the age of 235 days until reaching the age of puberty and the emission factor average recording was 49.70 and 101.66 kg CH_4 for the systems C and FR, respectively. The other main contributor to greenhouse gas emissions was the carbon dioxide from fossils with a contribution of 65% of feeding from system C.

Table 4
Main emissions in air (kg CO_2-eq per 1 kg of fat and protein corrected milk) contributing to climate change from systems free-ranging (FR) and confined (C).

Emission	System FR	System C
Methane biogenic, enteric	1.84	1.26
Methane biogenic, manure	0.52	1.24
Carbon dioxide, fossil	1.18	1.20
Dinitrogen monoxide	0.51	0.62
Methane	0.10	0.15

3.2. Terrestrial acidification (TA)

The environmental impact generated by the two global processes per 1 kg of FPCM is reported in Table 3. The global processes FR system showed a lower TA as compared with the global processes C system. The reduction of the impact was around 10%. In the present study we observed levels of SO_2-eq. kg-1 FPCM much lower than those reported by Pirlo et al. (2014a) (65 g) and closer to those reported by Guerci et al. (2013) for grazing dairy cattle (7.44 g). These different results may be attributed to the lower use of inorganic fertilisers in pasture-based systems. The lactation phase represented about 48% of the global process with feeding accounting for 82% and ammonia as the main compound emitted in air followed by nitrogen oxides and sulfur dioxide. A major role is also played by soybean meal transportation and the identification of alternative protein source locally produced such as faba bean may reduce the impact in terms of TA. Obviously, the reduction in TA was higher in the heifer phase (88%) than in the lactation phase (6%) when system FR was compared with system C.

Most of the impact of system C was due to on-farm activities, whereas in system FR only 32% of the impact could be attributed to these activities. In fact, in system FR no feed was produced and the animals mostly relied on pasture as feeding resource. Table 5 shows the main emissions responsible of TA. Ammonia is one of the primary causes of soil acidification and is accounted for in both the nutrient management and fertiliser application components of the soil acidification model. In the system C the ammonium was the first polluting substance followed by SO_2 and NO_X. The main process responsible for pollutant emissions in system C was the production of maize silage, which accounted for 41.1%, of the total emission, followed by transport activities in the farm (28.2%). The cultivation of one ha of maize silage needs high amounts of urea and an extensive use of machinery. In system FR the main activities involved in TA emissions were outside the farm and concerned the production of the feed supplementation offered to the animals during winter, and the faeces deposited directly onto pasture. Although Faugno et al. (2012) observed that buffalo manure shows a lower content of N as compared with dairy cattle, the higher rate of N and organic matter deposition in “stock camps”, where FR animals tend to concentrate manure, may result in increased acidification potential (Cayley et al., 2002). In pigs, however, outdoor systems can markedly reduce ammonia emissions due to the higher aeration levels and per animal space allowance, which may help maintaining low the temperature, a key ammonia emission controlling factor (Basset et al., 2007).

3.3. Marine eutrophication (ME)

The environmental impact generated by the two global processes per 1 kg of FPCM is reported in Table 3. The use of free ranging from 8 months to puberty determined a 6% reduction in terms of ME. In the lactation phase we observed a 5% reduction, whereas in the heifer phase the reduction reached 80%. The total impact for ME was higher in system C than in system FR although both similar to those reported for French dairy production systems (Lehuger et al., 2009). The lactation phase accounted for 50% of the

Table 5
Main emissions in air contributing to terrestrial acidification (g SO_2-eq per 1 kg of fat and protein corrected milk) from systems free-ranging (FR) and confined (C).

Emission	System FR	System C
Ammonia	5.84	6.51
Sulfur dioxide	4.19	4.56
Nitrogen oxides	4.10	4.47

global process with feeding as the main operation involved due to the use of soybean meal. Nitrate and phoshate leakage were the major responsible of ME. This result can be attributed to the higher on-farm eutrophication impact observed in system C as compared with system FR. In system C eutrophication consisted mainly of NO_3- and PO4-3 leaching, NH_3 volatilization during fertilisation for feed production and NH_3 volatilization from manure spreading (O'Brien et al., 2012). The main source of pollution was the production of maize silage (41,1%), as also observed by Bartl et al. (2011). Emissions of nitrogen pollutants (NH_3 and NO_{3-}) are major sources for eutrophication, which are generally connected to several agricultural practices and to animal based productions in particular (Cederberg and Mattsson, 2000). Table 6 shows nitrate and nitrogen oxides as the dominant sources of eutrophication, as also found by other authors (Thomassen et al., 2008; O'Brien et al., 2012). In system C, NO_3^- from the cultivation of forage maize (41.1% of all NO_3^- emissions) may play an important role in the potential eutrophication impact as this system is located in the River Sele Plain, which is characterized by coastal and soil erodibility (Diodato et al., 2011a), with high to very high soil erosion hazard (Diodato et al., 2011b). The Sele river flows into the Tyrrhenian Sea where P-eutrophication (mainly PO_4^-) may result in excessive growth of algae and higher plants.

3.4. Agricultural land occupation (ALO)

Agricultural land occupation was the sole category where system FR showed a higher impact as compared with system C with a 7% increment in agricultural land occupation (Table 3). In the lactation phase the increment was 5%, whereas in the heifer phase the increment reached 95%. This result can be attributed to the use of permanent pasture in system FR. In particular, in this system the category with the highest impact was occupation pasture and meadow extensive (69%). This impact category represented 41% of the total impact in system C. Conversely, the category occupation arable non irrigated intensive had a higher impact in system C (27%) than in system FR (14%).

As expected, land occupation was mostly determined by the lactation phase (50% of the entire process). Obviously, feeding had the highest impact with meadow hay production playing the most important role. Most of the total land occupation was due to the use of arable and irrigated arable lands.

In agreement with Bartl et al. (2011), in system FR permanent pastures contributed for 89.7% of all land occupation. In intensive systems the production of concentrates for animal feeding purposes represents the main source of land occupation, which is mainly dependent on the yield of the cultivated crops (Elferink and Nonhebel, 2007). In our study the production of soybean meal contributed for 48.2% of all land occupation in system C, whereas the shed for livestock accounted for 10.1%. The calculations used by Simapro8.01 to determine the different impact categories, including land occupation, are based on equations and coefficients directly derived from the database of Econinvent (Nemecek and Schnetzer, 2011). Therefore, for this category the impact was calculated from the duration of land use and from the yield per area unit (Nemecek and Schnetzer, 2011), whereas it was not in any way considered the type of land used as permanent pasture. Conversely, other aspects should be also taken into account, such as accessibility, soil fertility, suitability for alternative more productive agricultural uses and degree of competition with other human activities (Nguyen et al., 2010). For instance, in our study the permanent pasture used in system FR was located in a hilly area (see Material and Methods) with difficult access by mechanical means, thus the only potential productive use was represented by livestock farming. In addition, the use of a natural pasture based diet markedly reduced the degree of competition with human nutrition, as the forages ingested by the animals could not be used for human consumption (Napolitano et al., 2005). Therefore, we suggest that the estimation of the impact categories related to land occupation would include aspects concerning the nature of the land (Braghieri et al., 2015). Bartl et al. (2011) studied two smallholder dairy enterprises located on the coast or in the mountains. They suggested that when a pasture-based system is compared with a confined system no evaluation of the impact on the environment due to mere land occupation should be done, rather the quality of land use should be taken into account, including aspects such as landscape ecology, biodiversity conservation, animal welfare, etc. Accordingly, Nguyen et al. (2010) noted that the assessment of the impact of livestock production on land occupation should take into account the potential role played by that land in alternative scenarios, such as forestry, potentially sequestrating a higher amount of carbon, and the consequent increased demand of land for feed to be used for animal nutrition. In system FR the natural pasture was part of a Mediterranean maquis mixed with bushes and trees, thus already expressing its potential for carbon sequestration.

Table 6
Main emissions in air and in water contributing to marine eutrophication (g N-eq per 1 kg of fat and protein corrected milk) from systems free-ranging (FR) and confined (C).

Emission	Global process - FR	Global process - C
Nitrate	17.02	18.33
Nitrogen oxides	0.31	0.34
Ammonia	0.20	0.22

3.5. Water depletion (WD)

WD is another important indicator of the sustainability of animal production practices. The environmental impact generated by the two farming systems for 1 kg of FPCM is reported in Table 3. System FR allows an 11% reduction corresponding to 0.45 m^3 per 1 kg di FPCM as compared with system C. This reduction is higher in the heifer phase, when the animals were able to drink directly from a stream flowing in the range. No data are available on WD in dairy buffaloes, while conflicting results are available for dairy cattle: in Noord-Brabant (Netherlands) De Boer et al. (2013) observed that 66 l of consumptive water was needed for 1 kg of FPCM, whereas at world level it has been reported a water footprint of 1207 m^3/ton of milk (Mekonnen and Hoekstra, 2012) and a consumption of 544 l per 1 kg di FPCM (Mekonnen and Hoekstra, 2010). In the other impact categories dairy buffaloes (Pirlo et al., 2014a) showed impacts 4-fold higher than dairy cattle (Guerci et al., 2013) due to the lower milk production (roughly 4-fold lower even in terms of FPCM), even though input levels and categories, animal and farm dimensions were roughly similar. The higher difference with respect to the De Boer et al.'s (2013) data may be due to the higher water requirements for maize silage production in southern Italy (Martiniello and Claps, 2014). In fact, in both systems the main process affecting WD was represented by maize silage production, which accounts for 36% and 42% in systems FR and C, respectively. The difference observed between the two systems can be attributed to the fact that the animals from system FR did not receive maize silage during the heifer phase. The second process affecting WD was transport (28 and 29% for FR and C systems, respectively), which was only 1% less in the system FR due to the lower transport activities in the farm.

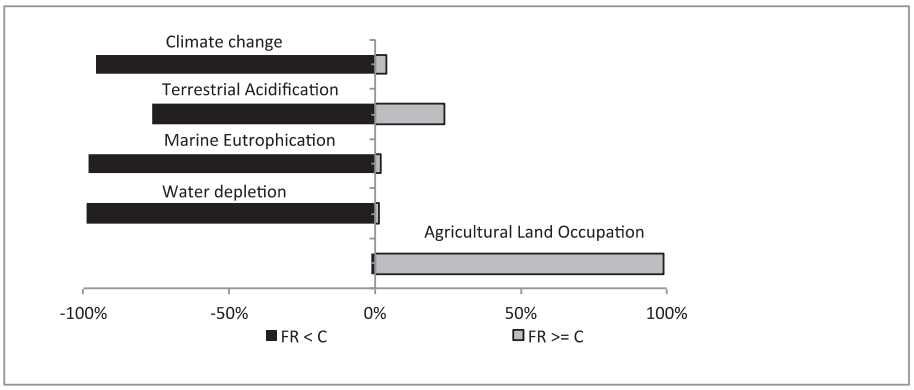

Fig. 2. Monte Carlo results of the comparison between free-ranging (FR) and confined systems (C) in terms of Climate Change, Terrestrial Acidification, Marine Eutrophication, Water depletion and Agricultural land occupation.

3.6. Monte Carlo analysis

Fig. 2 shows the graphical results of the uncertainty analysis conducted to assess the significance of the multiple comparisons between the farm environmental performances of the two global processes (i.e. that including heifer free-ranging vs. that including heifer kept in confinement). Significant differences were observed for CC, ME, WD (with higher impacts for the global process including heifers kept in confinement) and agriculture land occupation (with higher impacts for the global process including free-ranging heifers), whereas TA only tended to be higher in the global process including heifers kept in confinement.

4. Conclusions

Our results represent the first example of study assessing the environmental impact of a dairy farming system with the inclusion of an unproductive phase conducted in extensive conditions (i.e. natural pasture in the Mediterranean region). Our LCA study showed large differences between the two farming systems for all parameters. Heifer free-ranging reduced water consumption and most of the polluting agents both in the atmosphere and in water. At category level we observed a reduction of the impact on climate change (9%), terrestrial acidification (10%), marine eutrophication (6%) and water depletion (11%), whereas agriculture land occupation was 7% higher.

In conclusion, we clearly showed that the conduction of part of dairy buffalo farming (i.e. the unproductive phase from 7 to 8 months of age to puberty) on natural pasture is possible and it also allows the reduction of several sources of pollution while reducing the production costs, hence the economic sustainability, both in terms of fixed (the barn becomes unnecessary in the heifer phase) and variable costs (part of the feed is directly gathered from natural pasture by the animals). Although this system requires a greater use of land, parameters concerning the quality of land use (landscape ecology, biodiversity conservation, animal welfare standards, etc.) should be included for a more accurate assessment of this aspect, rather than taking into account only duration of land use and yield per area unit. Therefore, we suggest that future research should include aspects concerning the nature of the occupied land and the eco-system services provided by buffalo free-ranging.

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